National Park Service
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The northern islands of Channel Islands National Park (left to right: San Miguel, Santa Rosa, Santa Cruz, Anacapa) and mainland California (top: City of Santa Barbara, right: Cities of Ventura and Oxnard) in a natural color Landsat scene, 6:30 PM, May 10, 2015. Stripes over the water come from the satellite sensor sweep. (Data U.S. Geological Survey, Image P. Gonzalez)

Climate Change Trends, Vulnerabilities, and Ecosystem Carbon in Channel Islands National Park, California

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Abstract

Greenhouse gas emissions from human activities have caused global climate change and widespread impacts on physical and ecological systems. To assist in resource management in Channel Islands National Park (NP) under climate change, this report presents results of original spatial analyses of historical and projected climate change trends and ecosystem carbon and a review of published research on impacts and vulnerabilities. Spatial analyses of historical temperature and precipitation at 800 m spatial resolution show the changes that the area within the boundaries of Channel Islands NP has experienced. Average annual temperature from 1950 to 2010 increased at a statistically significant rate of 1.4 ± 0.6ºC (2.5 ± 1.1ºF.) per century (mean ± standard error), with the greatest increase in spring. Total annual precipitation from 1950 to 2010 increased at a rate of 38 ± 28% per century, with the greatest increase in winter, but the rates were not statistically significant. Regional and global analyses of field data that includes data from southern California have detected ecological changes that have been attributed to human climate change. At Santa Monica, the tidal gauge closest to the park shows a rise in sea level at a statistically significant rate of 14 ± 3.4 cm (6 ± 1.3 in.) per century from 1933 to 2014. Analyses of ocean waters, including those of the Pacific Ocean off California, have shown increases in sea surface temperatures and acidity, both attributable to human climate change. Regional analyses of bird counts from across the United States (US), including southern California, show that climate change shifted winter bird ranges northward at a rate of 0.5 ± 0.3 km (0.3 ± 0.2 mi.) per year from 1974 to 2004. If the world does not reduce greenhouse gas emissions, projections under the four emissions scenarios of the Intergovernmental Panel on Climate Change (IPCC) indicate annual average temperature increases for the park of up to 3.5 ± 0.8ºC (6.3 ± 1.4º F.) (mean ± standard deviation) from 2000 to 2100. Model projections show possible increases of total annual precipitation of 5-7% for the four scenarios. Published analyses for the area including the national park indicate numerous vulnerabilities to future climate change, including inundation and erosion of coastal areas, changes to gray whales, sea stars, and mussels, and potential increased mortality of endangered plants such as soft-leaved paintbrush. Aboveground vegetation in the park stores an amount of carbon equivalent to the annual emissions of 24 000 ± 17 000 Americans. From 2001 to 2010, ecosystem carbon increased on one-third of the area of Santa Rosa Island and the eastern end of Santa Cruz Island, coinciding with ecosystem restoration in those areas during that time period. As a whole, the national park did not experience a statistically significant change in aboveground carbon.

Introduction

Greenhouse gas emissions from power plants, motor vehicles, deforestation, and other human activities have increased temperatures around the world and changed other climate factors in the 20th and early 21st centuries (IPCC 2013). Field measurements show that climate change is fundamentally altering ecosystems by shifting biomes, contributing to species extinctions, and causing numerous other changes (IPCC 2014). To assist Channel Islands NP in the integration of climate change science into resource management, this report presents results of original spatial analyses of historical and projected climate change and ecosystem carbon and a summary of published scientific findings on climate change impacts and vulnerabilities.

The historical analyses (Wang et al., in preparation) use previously published spatial climate data layers at 800 m spatial resolution, derived from point weather station measurements using the Parameter-elevation Relationships on Independent Slopes Model (PRISM; Daly et al. 2008). The area covered by the analyses is the area within park boundaries. The historical climate trends derive from linear regression of temperature and precipitation time series, with the statistical probability of significance corrected for temporal autocorrelation.

The analyses of future projections (Wang et al., in preparation) use output of all available general circulation models (GCMs) of the atmosphere in the Coupled Model Intercomparison Project Phase 5 (CMIP5) data set established for the most recent IPCC report (IPCC 2013). The coarse GCM output, often at spatial resolutions of up to 200 km, has been downscaled to 800 m spatial resolution using bias correction and spatial disaggregation (BCSD; Wood et al. 2004).

The information on climate change impacts and vulnerability comes from a search of scientific literature for published research that used field data from Channel Islands NP or spatial analyses of the area that includes the park.

Historical Climate Changes

Mean annual temperature showed a statistically significant increase in the periods 1895-2010 and 1950-2010 (Figure 1, Table 1). The period 1950-2010 gives a more robust time series than the period 1895-2010 because the U.S. Government established a substantial number of weather stations in the late 1940s and the weather station network has been relatively stable since then. Spatial data from the longer period relies on fewer weather stations and a network that enlarged irregularly before the 1940s. The 1950-2010 trends show significant warming in spring and summer with the greatest rate of warming in spring (Table 1). The highest rates of warming have occurred in upper elevations of Santa Cruz Island and on Santa Barbara Island (Figure 2).

Total annual precipitation showed an increase from 1950 to 2010, but the rate has not been statistically significant (Figure 3, Table 2). Winter (December-February) precipitation increased at a rate of 58 ± 36% per century. Rates of precipitation tended to increase towards that south, with the greatest rates on Anacapa and Santa Barbara Islands (Figure 4).

Climate change has increased the frequency of heat waves, heavy rainstorms, and other extreme events in some parts of the world (IPCC 2013). National Oceanic and Atmospheric Administration (NOAA) analyses of weather station data show an increase in the southwestern US of heavy storms, with the decade 1991-2000 experiencing an increase of 25% in five-year storms (a storm with more precipitation than any other storm in five years), compared to the 1901-1960 average (Walsh et al. 2014). NOAA analyses show a 5% increase in the amount of precipitation falling in the heaviest 1% of all daily storm events from 1958 to 2012 in the southwestern U.S. (Walsh et al. 2014).

Historical Impacts

A search of scientific literature found a few published regional and global analyses of field data that include data from southern California and have detected physical or ecological changes that have been attributed to human climate change and not other factors. Measurements of sea surface temperatures in southern California and around the world have found warming of the top 75 m of ocean water at a rate of 1.1 ± 0.2ºC (2 ± 0.4ºF.) per century from 1971 to 2010 (IPCC 2013). Analyses of tidal gauge measurements around the world have detected a statistically significant rise in global sea level of 19 ± 2 cm (7 ± 1 in.) from 1901 to 2010 with analyses of potential causal factors attributing the rise to human climate change (Church and White 2011, IPCC 2013). At Santa Monica, the tidal gauge closest to the park shows a rise in sea level at a statistically significant rate of 14 ± 3.4 cm (6 ± 1.3 in.) per century from 1933 to 2014 (NOAA data, <http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=9410840>).

Increased atmospheric carbon dioxide (CO_2) concentrations from human activities have increased the acidity of ocean water around the world by 0.1 pH units since ~1750 (IPCC 2013). This occurs when CO_2 dissolves in water and forms carbonic acid. High acidity can dissolve the shells of many marine species.

Analyses of Audubon Christmas Bird Count data across the United States, including counts in southern California, detected a northward shift of winter ranges of a set of 254 bird species at an average rate of 0.5 ± 0.3 km (0.3 ± 0.2 mi.) per year from 1975 to 2004, attributable to human climate change and not other factors (La Sorte and Thompson 2007).

Other research has examined observations consistent with, but not formally attributed to, human climate change. It is important to note that the changes, if observed, have not necessary been detected (shown statistically significantly different than historical variability) and they have not been attributed to human climate change. At eight sites on the four largest islands of the park, species richness of mussels declined ~70% between the 1960s and 2002, consistent with increased water temperatures (Smith et al. 2006). Published analyses consistently indicate that winds in the California Current system have intensified since the 1940s (Sydeman et al. 2014). An intensification of winds in eastern boundary current systems such as the California Current are consistent with steeper temperature and sea level pressure gradients between the oceans and the continents, induced by climate change. Changes in the California Current could alter ocean upwelling and affect the marine life dependent on nutrients in these areas.

Future Climate Projections

IPCC has coordinated research groups to project possible future climates under four defined greenhouse gas emissions scenarios, called representative concentration pathways (RCPs; Moss et al. 2010). The four emissions scenarios are RCP2.6 (reduced emissions from increased energy efficiency and installation of renewable energy), RCP4.5 (low emissions), RCP6.0 (high emissions, somewhat lower than continued current practices), and RCP8.5 (highest emissions due to lack of emissions reductions).

If the world does not reduce emissions from power plants, cars, and deforestation by 40-70%, GCMs project substantial warming and slight increases in precipitation. The temperature and precipitation projections from 33 GCMs form a cloud of potential future climates (Figure 5). GCMs project potential increases in annual average temperature within park boundaries greater than historical 20th century warming by 2050 (Table 3) and up to double historical warming by 2100 (Table 4). Projected temperature increases do not show much spatial variation across the park. Models project the greatest temperature increases in the autumn.

The mean of the ensemble of GCMs gives a projection of increased precipitation under all emissions scenarios. The mean of the GCM ensemble reflects the central tendency of the projections, but the uncertainty of any projection of the future can be large. In the case of southern California, the GCMs do not agree on precipitation projections, with over half projecting increases, but many projecting decreases (Figure 5).

Projections indicate potential changes in the frequency of extreme temperature and precipitation events. Under the highest emissions scenario, models project up to 25 more days per year with a maximum temperature > 35ºC (95ºF.) and an increase in 20-year storms (a storm with more precipitation than any other storm in 20 years) to once every 5-10 years (Walsh et al. 2014).

Projected Vulnerabilities

If the world does not reduce emissions from power plants, cars, and deforestation, climate change could continue to raise sea level globally 26-55 cm (10-22 inches) by 2100 for the lowest emissions scenario and 52-98 cm (20-39 inches) for the highest scenario (IPCC 2013). Storm surge would occur over and above the projected sea level rise, with models projecting more frequent and intense coastal flooding (NPS research on sea level rise and storm surge in individual parks is in progress by Dr. Maria Caffrey). An analysis of the vulnerability of the coasts of Channel Islands NP to sea level rise has analyzed geomorphology, historical shoreline change, regional coastal slope, relative sea level change, mean wave height, and mean tidal range for 1.7 km segments of shoreline (Pendleton et al. 2010). Approximately half of the park shoreline is highly vulnerable due to exposed sandy stretches and high waves. Shoreline with rock cliffs, steep slopes, and wave heights are less vulnerable.

Under high emissions, ocean acidification could deplete near-shore waters of calcium carbonate for almost all of the year (Gruber et al. 2012), rendering vulnerable many marine species. Acidity reduces the water concentrations of calcium carbonate that many marine species, including pteropods, shellfish, and corals, require for building shells for survival.

Around Santa Cruz Island, sensitivities of sea stars (*Pisaster ochraceus*) and mussels (*Mytilus californianus*) to water temperature increases in the intertidal zone depends on location (Broitman et al. 2009). Body temperatures of sea stars were consistently lower than those of mussels and showed lower daily fluctuations. Body temperatures of the two organisms varied together in warmer southern waters, but were less synchronized in cooler northwest waters.

Intensification of winds under climate change could increase upwelling in the California Current system under climate change (Sydeman et al. 2014), which could benefit marine populations by increasing nutrient inputs into surface waters, cause harm by disrupting food webs, or alter diet composition of marine birds in the park (Sydeman et al. 2001). Models under very high emissions, however, do not agree on projections of changes in the California Current (Wang et al. 2015).

Gray whales (*Eschrichtius robustus*), which migrate through the park, may spend more time in Arctic waters due to longer and earlier ice-free conditions, changing the timing and duration of their passage through California waters (Moore and Huntington 2008).

On Santa Cruz Island, water from fog and the cooling effect of overcast skies substantially reduces drought stress and seedling mortality in bishop pine (*Pinus muricata*), suggesting vulnerability if climate change alters these conditions (Williams et al. 2008, Fischer et al. 2009, Carbone et al. 2013). On Santa Rosa Island, population sizes and growth rates of three listed endangered species, the annual plants Hoffmann's slender-flowered gilia (*Gilia tenuiflora* ssp. *hoffmannii*), Northern island phacelia (*Phacelia insularis* var. *insularis*), and Santa Cruz Island chicory (*Malacothrix indecora*), are correlated to the temperature after the first major storm event (Levine et al. 2008). If climate change continues, higher temperatures after the first rains may reduce germination. On Santa Rosa Island, the listed endangered perennial plant soft-leaved paintbrush (*Castilleja mollis*) is vulnerable to decreased growth with hotter growing-season temperatures (McEachern et al. 2009).

The island scrub-jay (*Aphelocoma insularis*) and other birds are vulnerable to increased probabilities of West Nile Virus under warmer temperatures (Morrison et al. 2011, Harrigan et al. 2014).

Under a high emissions scenario, the invasiveness of yellow starthistle (*Centaurea solstitialis*) could increase (Bradley et al. 2009).

Ecosystem Carbon

Growing vegetation naturally removes carbon from the atmosphere, reducing the magnitude of climate change. Conversely, deforestation, wildfire, and other agents of tree mortality emit carbon to the atmosphere, exacerbating climate change. Determining the balance between ecosystem carbon emissions to the atmosphere and removals from the atmosphere is essential for tracking the role of ecosystems in climate change (IPCC 2013). Analyses of Landsat remote sensing and field measurements of biomass across the state of California have produced estimates of the carbon in aboveground vegetation for the grasslands, woodlands, forests, and other non-agricultural and non-urban areas of the state at 30 m spatial resolution (Gonzalez et al. 2015). Monte Carlo analyses of error in tree measurements, remote sensing, and the carbon fraction of biomass quantified the uncertainty of carbon stock change estimates.

In 2010, aboveground vegetation in Channel Islands NP contained 130 000 ± 91 000 tons of carbon (Table 7, Figure 7) (Gonzalez et al. 2015). This stock is equivalent to the greenhouse gases emitted in one year by 24 000 ± 17 000 Americans.

From 2001 to 2010, aboveground vegetation carbon increased on one-third of the land area of Santa Rosa Island and one-tenth of the land area of Santa Cruz Island, primary at its eastern end, exceeding the surface areas of losses (Figure 8). The carbon increases result from increased vegetation cover, coinciding with ecosystem restoration in those areas during that time period. Although the total surface area in the national park experiencing carbon increases (green areas in Figure 8) greatly exceeded the surface area experiencing carbon losses (small brown patches in Figure 8), the increases generally involved an increase of grassland cover with only a modest increase in carbon density (carbon per hectare), while the decreases often involved losses of shrub vegetation in chaparral with carbon densities 10-20 times greater than grassland. So, small areas of chaparral loss nullified the grassland gains. The mean change in aboveground carbon stock of the park from 2001 to 2010 showed a slight decrease, but, since the 95% confidence interval makes a slight increase numerically possible, the decrease was not statistically significant (Table 7).

Table 1. **Historical average temperatures** and temperature trends of the area within the boundaries of Channel Islands National Park. SD = standard deviation, SE = standard error, sig. = statistical significance, * $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$.

	1971-2000		1895-2010			1950-2010		
	mean	SD	trend	SE	sig.	trend	SE	sig.
	°C		°C century^{-1}			°C century^{-1}		
Annual	15	0.5	0.7	0.2	**	1.4	0.6	*
December-February	12.5	0.9	0.1	0.3		0.9	0.6	
March-May	13.7	1	0.7	0.3	*	2.3	0.9	*
June-August	17.3	0.7	1.2	0.3	***	1.7	0.7	*
September-November	16.4	0.7	0.7	0.3	*	0.7	0.6	
January	12.3	1.1	0.4	0.4		2.3	0.8	**
February	12.7	1.1	0.4	0.4		0.9	0.8	
March	12.9	1.3	0.7	0.4		2.6	0.9	**
April	13.6	1.3	0.3	0.4		1.6	1.2	
May	14.6	1.2	1.2	0.3	***	2.8	0.8	**
June	16.2	1	1	0.4	**	2.2	0.8	*
July	17.4	0.8	1.1	0.3	***	1.5	0.7	*
August	18.1	0.9	1.3	0.4	**	1.4	0.9	
September	18	1.3	1.3	0.4	**	1.2	0.9	
October	16.7	0.9	0.7	0.3	*	0.7	0.9	
November	14.3	1.3	0	0.4		0.3	0.8	
December	12.5	1.2	-0.5	0.4		-0.8	1	

Table 2. **Historical average precipitation** totals and precipitation trends of the area within the boundaries of Channel Islands National Park. SD = standard deviation, SE = standard error, sig. = statistical significance, * $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$.

	1971-2000		1895-2010			1950-2010		
	mean	SD	trend	SE	sig.	trend	SE	sig.
	mm y^{-1}		% $century^{-1}$			% $century^{-1}$		
Annual	410	190	11	11		38	28	
December-February	240	150	15	15		58	36	
March-May	110	80	-3	19		-3	51	
June-August	3	5	-24	48		-21	125	
September-November	53	42	14	21		-24	59	
January	85	84	0	24		25	56	
February	98	94	34	23		110	59	
March	83	68	-8	26		32	72	
April	21	25	19	33		-113	76	
May	7	17	-39	51		140	143	
June	1	2	-42	71		51	137	
July	0	1	-52	73		-214	209	
August	2	5	10	84		-24	261	
September	8	19	-60	59		-68	174	
October	13	16	10	34		280	104	**
November	32	32	30	35		-120	91	
December	56	47	19	23		85	65	

Table 3. **Projected temperature increases** (°C), 2000 to 2050, for the area within Channel Islands NP boundaries, from the average of all available general circulation model projections used for IPCC (2013). RCP = representative concentration pathway, SD = standard deviation.

	Emissions Scenarios							
	Reductions RCP2.6		Low RCP4.5		High RCP6.0		Highest RCP8.5	
	mean	SD	mean	SD	mean	SD	mean	SD
Annual	1.3	0.4	1.5	0.4	1.4	0.3	1.9	0.5
December-February	1.2	0.4	1.5	0.5	1.3	0.4	1.9	0.6
March-May	1.2	0.4	1.4	0.5	1.3	0.4	1.7	0.5
June-August	1.2	0.5	1.4	0.5	1.3	0.3	1.8	0.5
September-November	1.4	0.5	1.7	0.6	1.6	0.4	2.3	0.6
January	1.2	0.5	1.5	0.4	1.4	0.4	1.9	0.6
February	1.2	0.4	1.4	0.5	1.2	0.5	1.7	0.5
March	1.2	0.4	1.4	0.5	1.2	0.5	1.7	0.5
April	1.1	0.5	1.3	0.6	1.3	0.4	1.7	0.5
May	1.2	0.4	1.4	0.6	1.3	0.4	1.7	0.5
June	1.1	0.5	1.3	0.6	1.2	0.4	1.7	0.6
July	1.2	0.6	1.3	0.5	1.3	0.4	1.7	0.6
August	1.4	0.5	1.5	0.6	1.5	0.3	2	0.5
September	1.5	0.5	1.7	0.5	1.6	0.5	2.2	0.6
October	1.4	0.5	1.7	0.6	1.5	0.4	2.3	0.7
November	1.4	0.5	1.7	0.8	1.5	0.4	2.3	0.9
December	1.2	0.5	1.6	0.7	1.4	0.4	2.1	0.8

Table 4. **Projected temperature increases** (ºC), 2000 to 2100, for the area within Channel Islands NP boundaries, from the average of all available general circulation model projections used for IPCC (2013). RCP = representative concentration pathway, SD = standard deviation.

	Emissions Scenarios							
	Reductions RCP2.6		Low RCP4.5		High RCP6.0		Highest RCP8.5	
	mean	SD	mean	SD	mean	SD	mean	SD
Annual	1.3	0.5	2	0.6	2.3	0.6	3.5	0.8
December-February	1.3	0.5	2	0.6	2.3	0.7	3.5	0.9
March-May	1.2	0.5	1.8	0.5	2.1	0.6	3.2	0.7
June-August	1.2	0.6	1.9	0.6	2.2	0.6	3.3	0.8
September-November	1.5	0.6	2.3	0.8	2.5	0.7	4	1
January	1.4	0.5	2	0.6	2.3	0.7	3.5	0.8
February	1.3	0.5	1.9	0.6	2.2	0.7	3.3	0.8
March	1.3	0.6	1.8	0.6	2.2	0.6	3.2	0.8
April	1.2	0.5	1.8	0.6	2.1	0.6	3.2	0.7
May	1.2	0.5	1.9	0.6	2.1	0.6	3.2	0.7
June	1.2	0.6	1.8	0.7	2.1	0.6	3.2	0.8
July	1.1	0.7	1.8	0.7	2.1	0.7	3.2	0.8
August	1.3	0.6	2	0.7	2.4	0.6	3.5	0.8
September	1.5	0.6	2.3	0.7	2.5	0.7	3.9	0.9
October	1.5	0.7	2.4	0.8	2.5	0.8	4.1	1.1
November	1.4	0.6	2.3	1	2.5	0.7	4	1.2
December	1.4	0.5	2.1	0.9	2.3	0.7	3.7	1.2

Table 5. **Projected precipitation changes** (%), 2000 to 2050, for the area within Channel Islands NP boundaries, from the average of all available general circulation model projections used for IPCC (2013). RCP = representative concentration pathway, SD = standard deviation.

	Emissions Scenarios							
	Reductions RCP2.6		Low RCP4.5		High RCP6.0		Highest RCP8.5	
	mean	SD	mean	SD	mean	SD	mean	SD
Annual	6	12	3	14	5	16	3	16
December-February	8	17	8	21	10	25	10	24
March-May	2	16	-2	19	-5	16	-6	26
June-August	45	73	57	77	35	48	54	99
September-November	4	20	-4	27	5	25	-7	25
January	18	30	10	29	15	35	20	34
February	6	28	10	29	11	35	9	31
March	5	19	-2	23	-1	24	-2	27
April	0	26	-2	28	-14	22	-11	43
May	-3	59	6	96	4	56	1	85
June	23	78	22	64	11	77	14	90
July	92	112	79	147	91	113	79	134
August	71	140	119	193	82	148	114	150
September	43	80	58	128	55	97	41	88
October	18	41	8	53	30	64	13	54
November	-4	22	-13	39	-7	26	-17	28
December	3	23	3	21	3	24	-1	27

Table 6. **Projected precipitation changes** (%), 2000 to 2100, for the area within Channel Islands NP boundaries, from the average of all available general circulation model projections used for IPCC (2013). RCP = representative concentration pathway, SD = standard deviation.

	Emissions Scenarios							
	Reductions RCP2.6		Low RCP4.5		High RCP6.0		Highest RCP8.5	
	mean	SD	mean	SD	mean	SD	mean	SD
Annual	7	13	5	12	5	18	6	20
December-February	7	16	11	20	10	29	18	32
March-May	8	20	-3	18	-2	20	-11	27
June-August	54	63	55	91	39	79	79	110
September-November	4	19	-3	31	-7	22	-12	22
January	10	23	17	29	16	36	30	44
February	7	27	15	29	13	40	22	42
March	8	27	-2	18	5	26	-4	24
April	9	33	-6	29	-12	29	-20	40
May	27	84	8	96	-8	62	-25	78
June	30	63	18	71	22	83	15	72
July	111	138	83	143	83	145	228	458
August	92	139	122	204	82	147	156	252
September	41	69	32	95	41	83	44	89
October	21	47	3	41	19	50	8	63
November	-4	21	-8	40	-18	24	-22	31
December	3	17	-4	25	2	22	-2	24

Table 7. **Ecosystem Carbon**. Aboveground carbon (mean ± 95% confidence interval) and surface area of changes (Gonzalez et al. 2015).

		Santa Cruz Island	Santa Rosa Island	Channel Islands NP
Carbon stock 2010	thousand tons	130 ± 91	67 ± 70	220 ± 160
Carbon density 2010	tons ha^{-1}	5.3 ± 3.7	3.1 ± 3.3	4.3 ± 3.2
Change 2001-2010	thousand tons	-1.1 ± 1.6	-1.5 ± 1	-3.9 ± 4.2
Change 2001-2010	% of amount	-1 ± 1	-2 ± 2	-2 ± 2
Carbon increase	% of area	9	34	19
Carbon decrease	% of area	2	2	3

Figure 1.

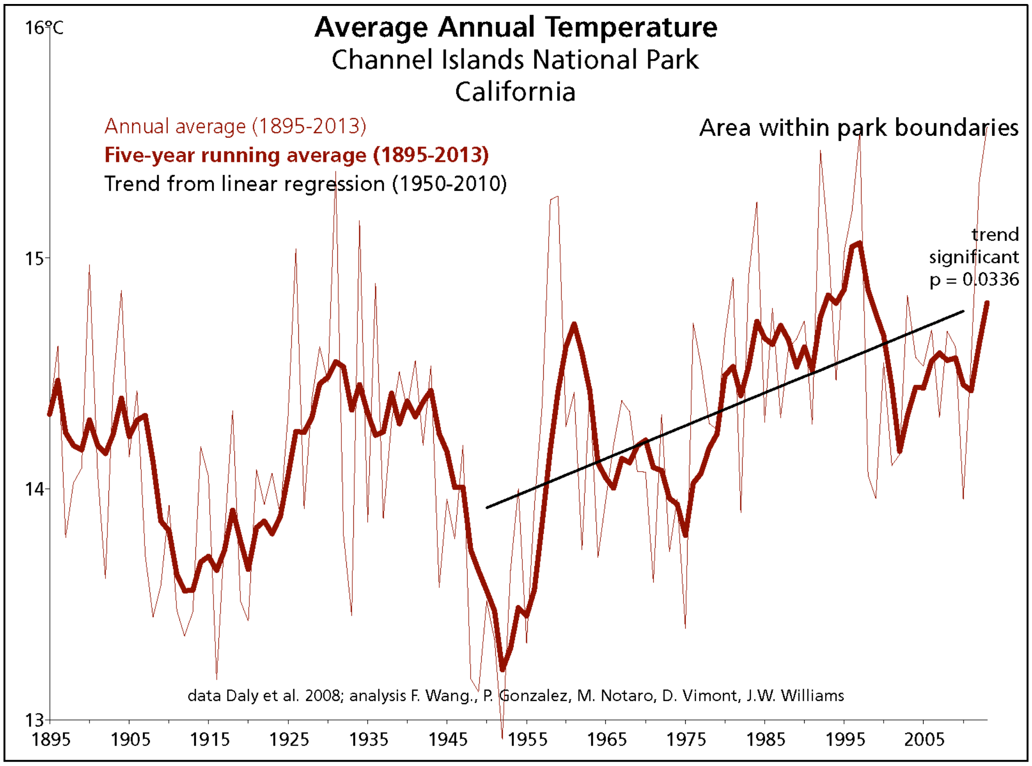

Average Annual Temperature
Channel Islands National Park
California
Annual average (1895-2013)
Five-year running average (1895-2013)
Trend from linear regression (1950-2010)
Area within park boundaries
trend
significant
p = 0.0336
16°C
15
14
13
1895
1905
1915
1925
1935
1945
1955
1965
1975
1985
1995
2005
data Daly et al. 2008; analysis F. Wang., P. Gonzalez, M. Notaro, D. Vimont, J.W. Williams

Figure 2.

Map 130 km square

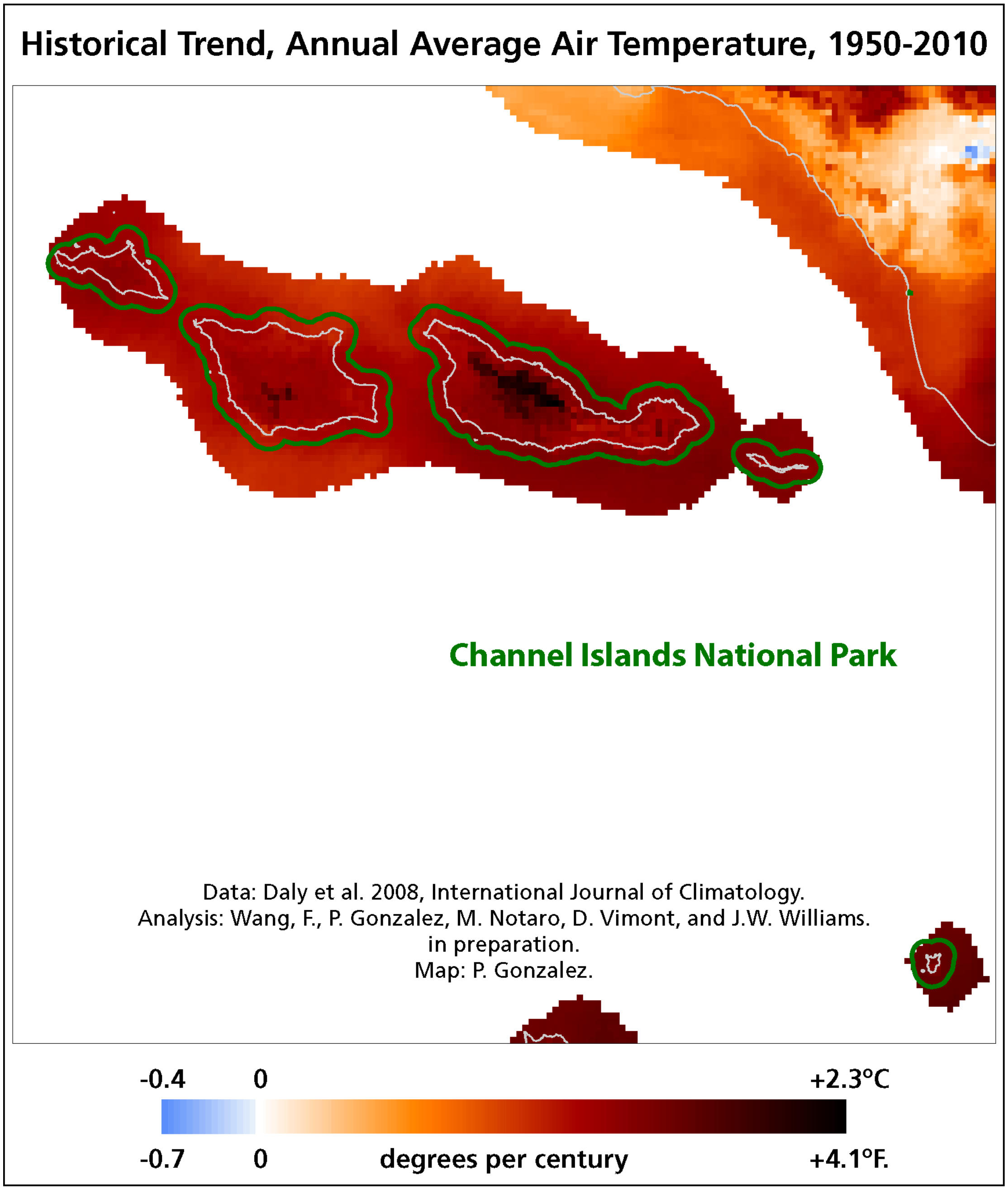


Figure 3.

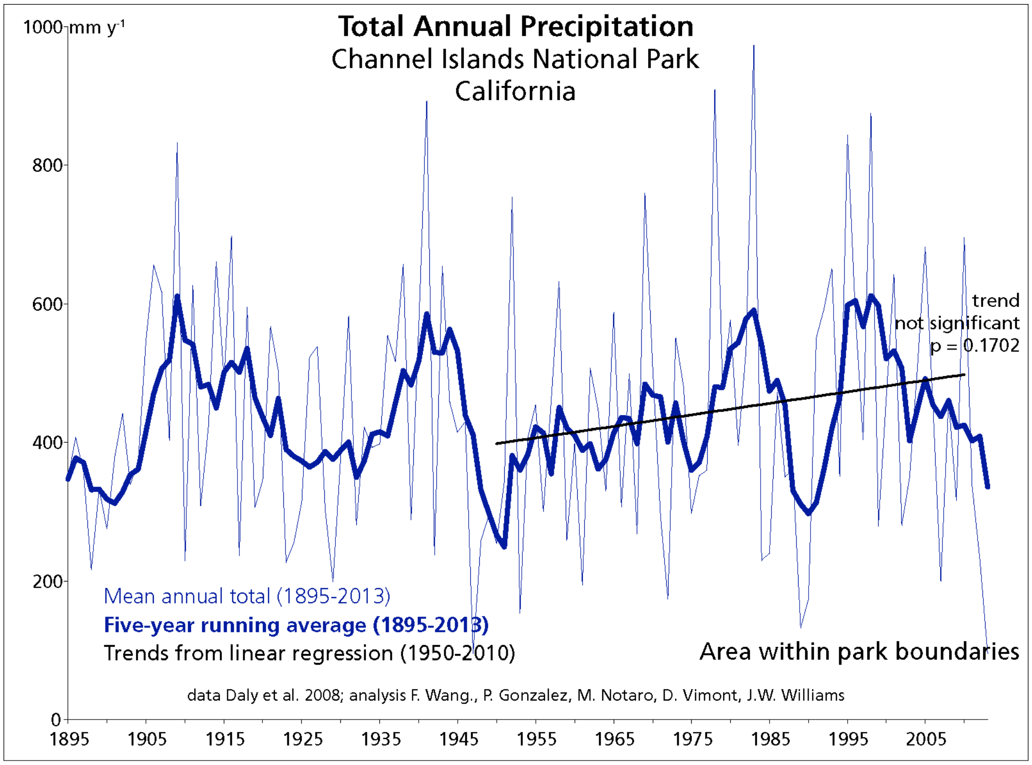

Total Annual Precipitation
Channel Islands National Park
California
1000 mm y-1
800
600
400
200
0
trend
not significant
p = 0.1702
Mean annual total (1895-2013)
Five-year running average (1895-2013)
Trends from linear regression (1950-2010)
Area within park boundaries
data Daly et al. 2008; analysis F. Wang., P. Gonzalez, M. Notaro, D. Vimont, J.W. Williams
1895
1905
1915
1925
1935
1945
1955
1965
1975
1985
1995
2005

Figure 4.

Map 130 km square

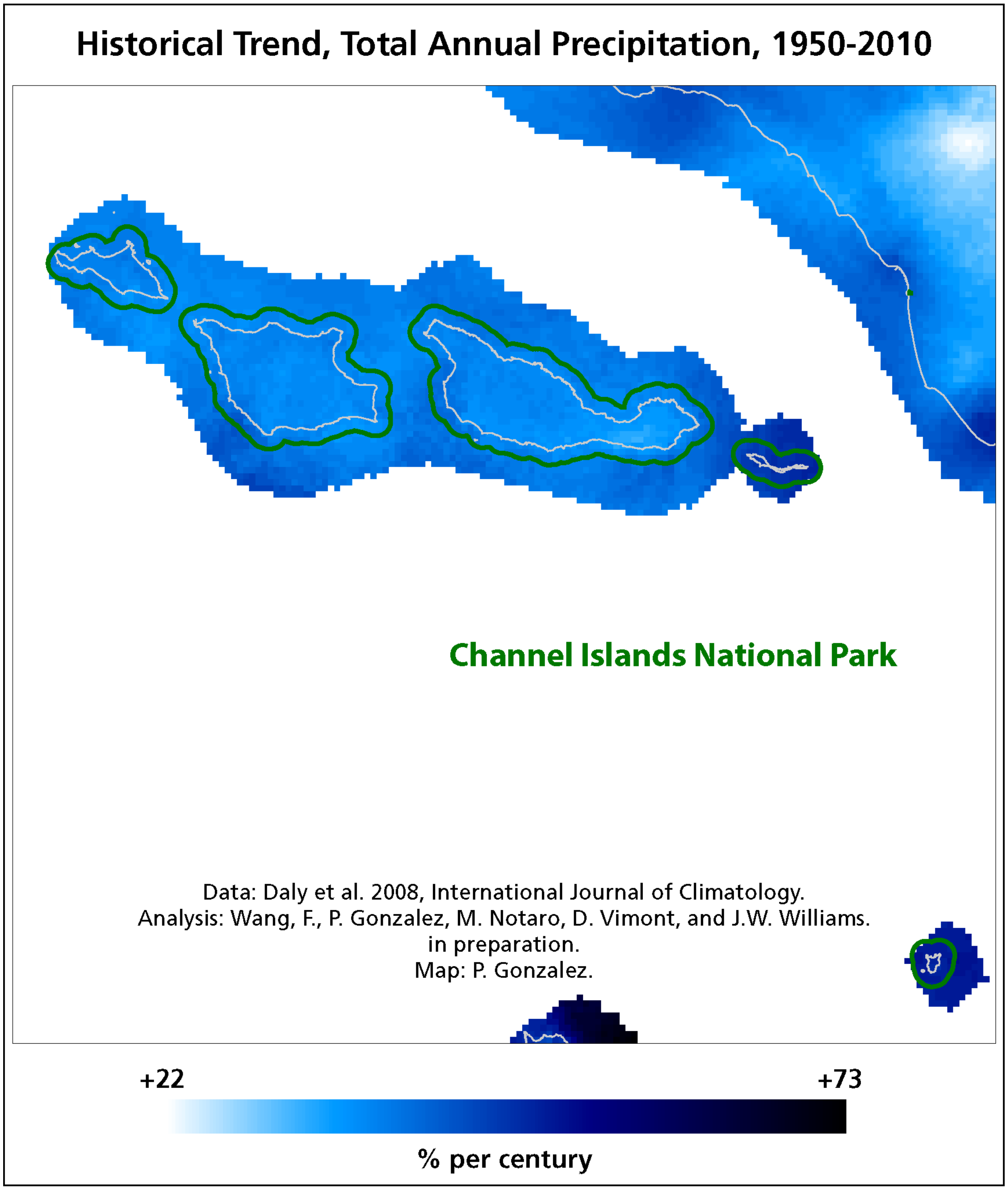


Figure 5. Projections of future climate for the area within park boundaries, relative to 1971-2000 average values. Each small dot is the output of a single GCM. The large color dots are the average values for the four IPCC emissions scenarios. The lines are the standard deviations of each emissions scenario average. (Data: IPCC 2013, Daly et al. 2008; Analysis: F. Wang, P. Gonzalez, M. Notaro, D. Vimont, J.W. Williams).

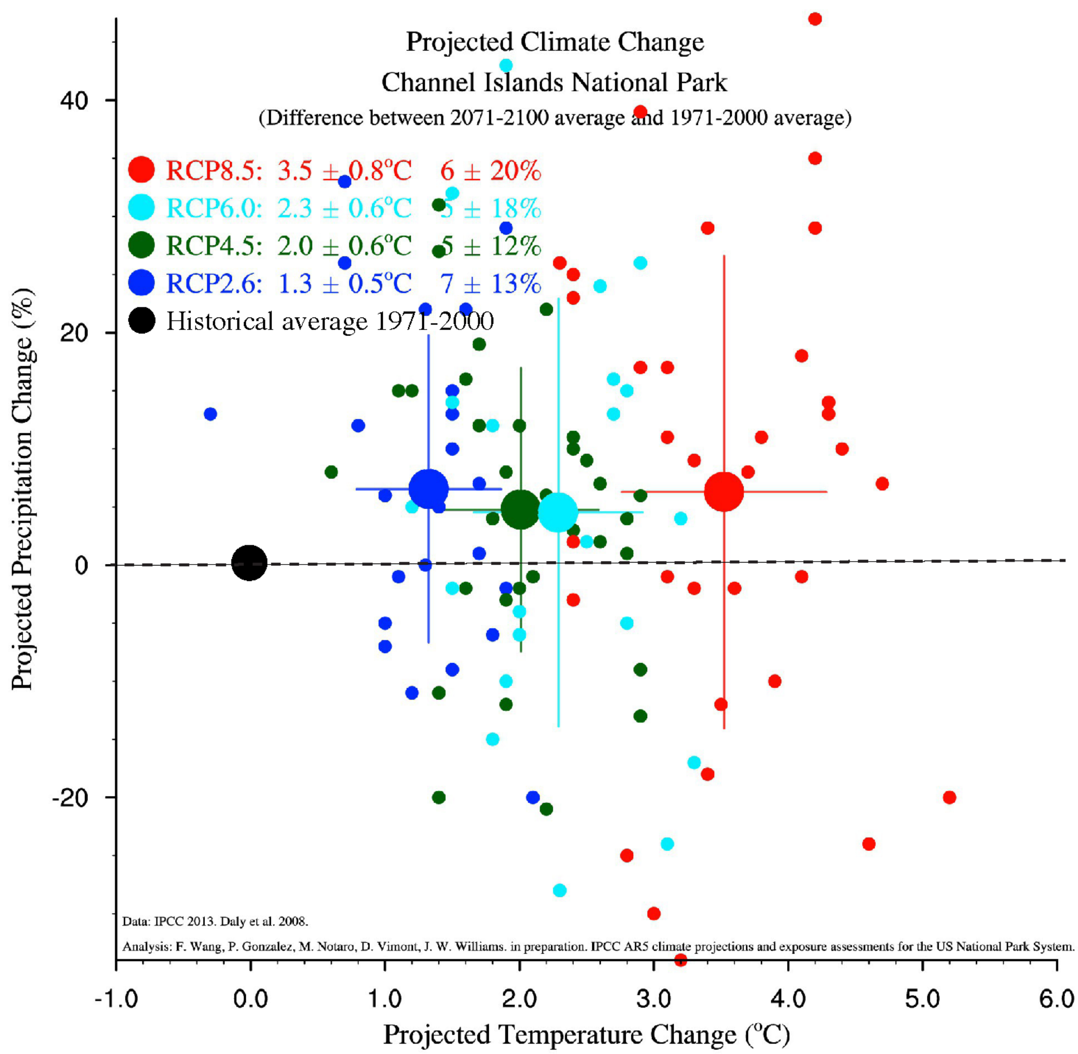
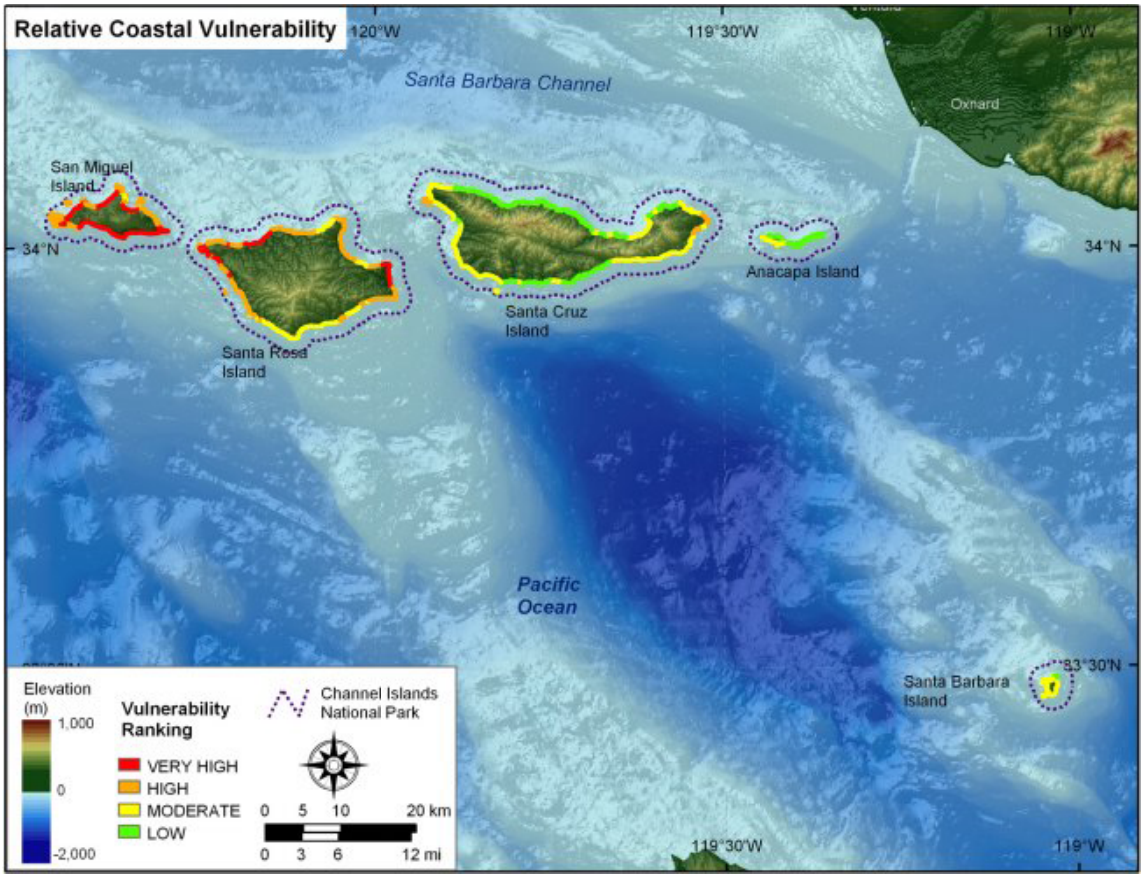


Figure 6. Relative coastal vulnerability (Pendleton et al. 2010). Shoreline colors represent the relative coastal vulnerability index determined from geomorphology, historical shoreline change, regional coastal slope, relative sea level change, mean wave height, and mean tidal range. Shoreline with sandy stretches of coast and high waves are the most highly vulnerable. Shoreline with rock cliffs, steep slopes, and wave heights are the least vulnerable.



Map Pendleton et al. (2010)

Figure 7.

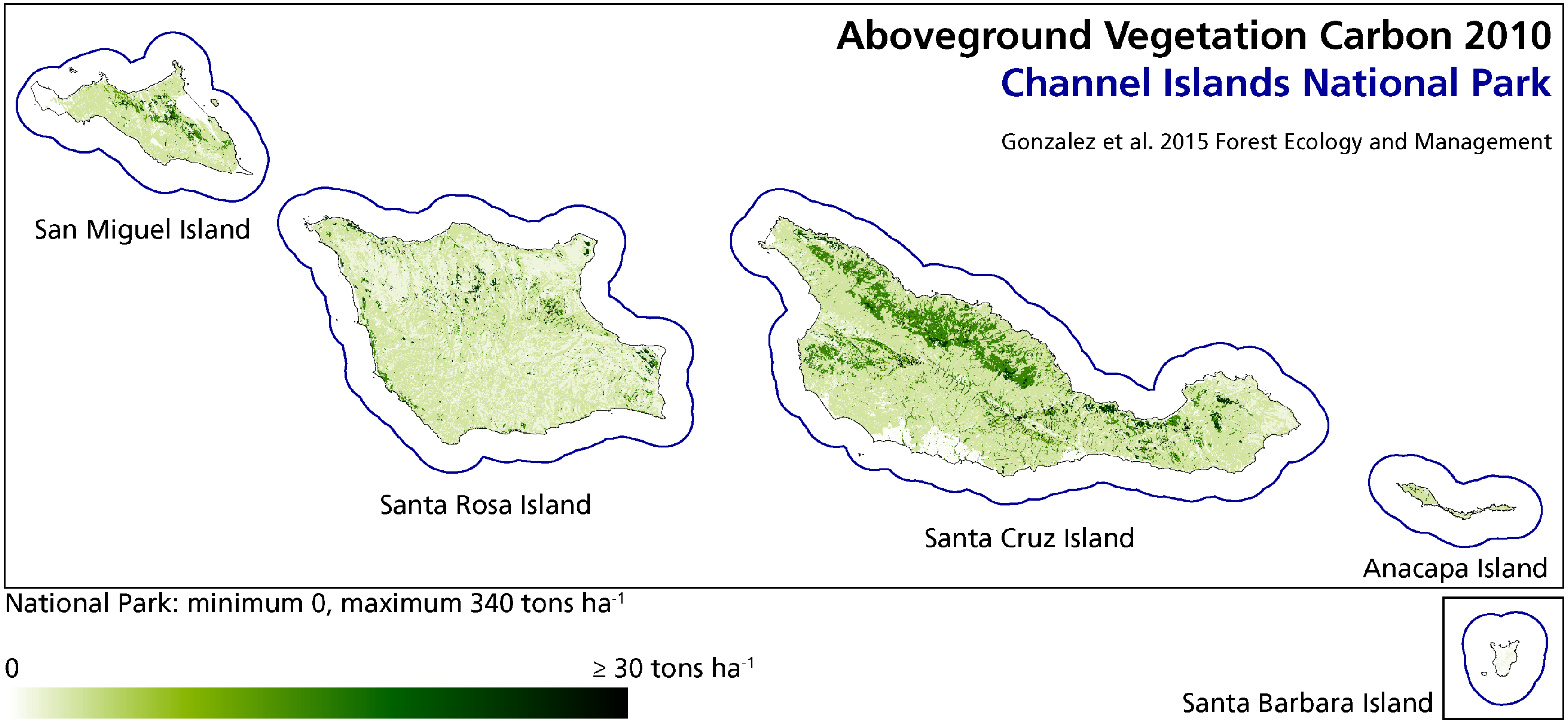
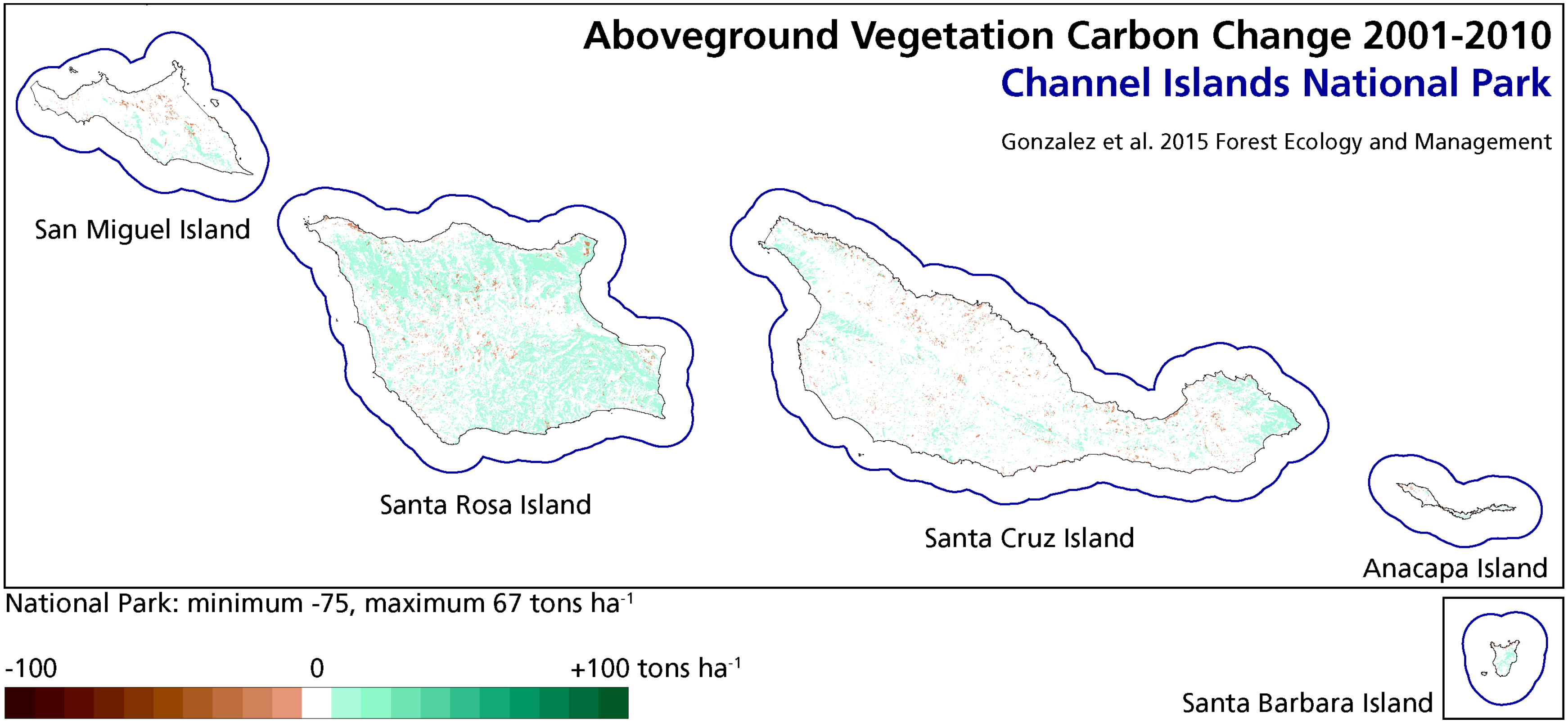

Aboveground Vegetation Carbon 2010
Channel Islands National Park
Gonzalez et al. 2015 Forest Ecology and Management
San Miguel Island
Santa Rosa Island
Santa Cruz Island
Anacapa Island
National Park: minimum 0, maximum 340 tons ha-1
0
≥ 30 tons ha-1
Santa Barbara Island

Figure 8.


Aboveground Vegetation Carbon Change 2001-2010
Channel Islands National Park
Gonzalez et al. 2015 Forest Ecology and Management
San Miguel Island
Santa Rosa Island
Santa Cruz Island
Anacapa Island
National Park: minimum -75, maximum 67 tons ha-1
-100
0
+100 tons ha-1
Santa Barbara Island

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